LASER WELDING OF DISSIMILAR MATERIAL

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CERTIFICATE

This is to certify that the thesis entitled "LASER WELDING OF DISSIMILAR MATERIAL" submitted by Sri Ashitosh Pandey in partial fulfillment of the requirements for the award of Bachelor of technology Degree in Mechanical Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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ABSTRACT

Very less work has been done on laser welding of dissimilar material. This project addresses optimization of process parameters in laser welding operation. Two sheets of stainless steel and copper are cut into small pieces. The small sheets of dimension 80mm*30mm*1mm were cut from the bigger sheet. Good surface finish is required for laser welding. So the small sheets are machined to remove bur. The small sheets were machined in grinding machine. Then they were filed to remove rest amount of bur present. Very less bur may also affect the welding output. So the surfaces to be welded were finished properly. Then the two small sheets were aligned on the table of the welding machine. The joint was placed in the right place by looking the joint in the eyepiece provided in the welding machine. Then the welding is simulated without laser. The simulation was seen on a screen attached with the welding machine. Simulation was done until the alignment was perfect. After simulation the two sheets of stainless steel and copper are welded together using laser beam. Similarly various pair of sheets of copper and stainless steel were welded. Two sets of experiment were done one with varying welding speed and the other with varying welding power. Tensile test and hardness test was done to each and every specimen. From those two sets of experiment the variation of harness and tensile strength with change in welding speed and welding power was observed.

1. INTRODUCTION

1.1 LASER

Light Amplification by Stimulated Emission of Radiation, LASER, is a mechanism for emitting light within the electromagnetic radiation region of the spectrum, via the process of stimulated emission. The emitted laser light is (usually) a spatially coherent, narrow low-divergence beam, that can be manipulated with lenses. In laser technology, “coherent light” denotes a light source that emits light of in-step waves of identical frequency and phase. The laser’s beam of coherent light differentiates it from light sources that emit incoherent light beams, of random phase varying with time and position; whereas the laser light is a narrow-wavelength electromagnetic spectrum monochromatic light; yet, there are lasers that emit a broad spectrum light, or simultaneously, at different wavelengths. In manufacturing, lasers are used for cutting, bending, and welding metal and other materials, and for "marking"—producing visible patterns such as letters by changing the properties of a material or by inscribing its surface. In science, lasers are used for many applications. One of the more common is laser spectroscopy, which typically takes advantage of the laser's well-defined wavelength or the possibility of generating very short pulses of light. Lasers are used by the military for range-finding, target designation, and illumination. Lasers have also begun to be tested for directed-energy weapons. Lasers are used in medicine for surgery, diagnostics, and therapeutic applications.

1.2 LASER WELDING

It is a welding technique used to join multiple pieces of metal through the use of a laser. The beam provides a concentrated heat source, allowing for narrow, deep welds and high welding rates. The process is frequently used in high volume applications, such as in the automotive industry.

Like electron beam welding (EBW), laser beam welding has high power density (on the order of 1 Megawatt/cm^2 (MW)) resulting in small heat-affected zones and high heating and cooling rates. The spot size of the laser can vary between 0.2 mm and 13 mm, though only smaller sizes are used for welding. The depth of penetration is proportional to the amount of power supplied, but is also dependent on the location of the focal point: penetration is maximized when the focal point is slightly below the surface of the work piece.

A continuous or pulsed laser beam may be used depending upon the application. Milliseconds long pulses are used to weld thin materials such as razor blades while continuous laser systems are employed for deep welds.

LBW is a versatile process, capable of welding carbon steels, stainless steel, aluminum, and titanium. Due to high cooling rates, cracking is a concern when welding high-carbon steels. The weld quality is high, similar to that of electron beam welding. The speed of welding is proportional to the amount of power supplied but also depends on the type and thickness of the work pieces. [13]The high power capability of gas lasers make them especially suitable for high volume applications. LBW is particularly dominant in the automotive industry.

Some of the advantages of LBW in comparison to EBW are as follows: the laser beam can be transmitted through air rather than requiring a vacuum, the process is easily automated with robotic machinery, x-rays are not generated, and LBW result in higher quality welds.

A derivative of LBW, laser-hybrid welding, combines the laser of LBW with an arc welding method such as gas metal arc welding. This combination allows for greater positioning flexibility, since GMAW supplies molten metal to fill the joint, and due to the use of a laser, increases the welding speed over what is normally possible with GMAW. Weld quality tends to be higher as well, since the potential for undercutting is reduced.

Welding techniques as TIG, MIG and resistance welding have been used for many years but they have many disadvantages. The main of the Disadvantages are

- lager fusion area
- larger heat-affected zones
- higher Shrinkage
- bigger deformations
- more defects such as cracks and porosity[1]

These disadvantages give rise to increased interest in laser welding method .the advantages of laser welding are

- Deep penetration
- high speed
- small heat-affected zone
- fine welding seam quality
- low heat input per unit volume
- fiber optic beam delivery
- ease of interface with robots[2]

Therefore, the application of laser welding in manufacturing is favorable. One of the final goals of the laser-welding application is to weld together to sheets of metal of different material and same thickness. Optimization technique is used to set the values of input parameters like laser power and weld velocity which is the controllable variables so as to get an optimum value of output.

2. LITERATURE REVIEW

The contents of this review was taken from "*Welding process developments and future trends".* Modern welding with its plethora of different processes began to replace the forge welding of antiquity about 100 years ago. Most artifacts, from the humble cooking pot to the modern petro-chemical plant, are made from more than one piece so the technology of joining has had a major influence on industrial development. Few modern constructions could exist without the now highly sophisticated technology of welding. Although the initial progress was a result of finding new methods of welding, the technology as a whole has only advanced to its current state, in which it is accepted almost without question and relied upon implicitly because engineers, metallurgists, specialists in NDT and many other professions have over the years found a common interest in welding. The various stages in this development can now be identified and seen in perspective.

In a recent paper (3) the author has proposed a chronology for welding development and suggested that we are now entering a new phase.

The development of the processes themselves is divided into the 'old' and the 'new periods. To an extent this terminology has the support of usage and it is certainly justified by the gap of almost thirty years between the invention of the last 'old' processes and the birth of the 'new' processes, of which the gas shielded arc processes were the first.

The whole chronology is as follows:

prior to 1880 Blacksmith period

80-1945 Old process period

a) Invention 1880-1914

b) Acceptance 1914-35

c) Production 1935-45

1945-1970 New process or 'scientific ‘period

1970-1984 Quality and performance period

1984- The intelligent welding system period

The 'Old' Process Period for several thousand years the black-smith had a monopoly on welding, but by the mid-19th Century the new discoveries of science had begun to offer the possibility of competing methods. As early as 1865 the English Mechanic carried notes for Do-it-yourself mechanics on 'Autogenous soldering' and 'Welding iron' by the use of air or oxy hydrogen flames. However, the main impetus came as a by-product of the search for illumination for the growing urban populations of Victorian times, acetylene burnt in air or with oxygen in 'limelight' and electric arc lights providing the basis materials, equipment and skills without which welding could not have been attempted or developed.

From its earliest days welding attracted the attention of scientists, academics and enthusiastic laymen. There is therefore no single point from which welding technology began. All we do know for sure is that it began in earnest just about 100 years ago. The oxy hydrogen flames mentioned above were not particularly effective and it was not until 1903 when a torch suitable for burning acetylene, which provides a hotter flame, was developed that gas welding took off. The carbide necessary for producing the acetylene was already made in large quantities for illumination purposes. In the mean-time, in 1886, resistance butt welding was invented by Elihu Thomson and exploited with considerable business acumen. The first butt welder in Britain was installed at Clarke Chapman's in 1890. Over 70 years later this machine was still in use in a blacksmith's shop. Carbon-arc welding, first tried by de Meritens in 1881, was further developed by Benardos in about1885 (4). Slavianov is normally given credit for inventing metal-arc welding in 1890, but his device was not unlike an arc lamp with automatic feed. This author agrees with Nunes (5) that bare wire metal-arc welding may have developed directly from carbon-arc quite independently of Slavianov. The straight substitution of a large diameter carbon electrode for a steel electrode of similar size would not have been successful, but the chance trial of a wire of smaller diameter would have provided a higher burn off rate and suitable arc conditions for manual operation.

Of course both carbon-arc and bare wire welding frequently gave unsatisfactory weld deposits from the metallurgical point of view. The carbon-arc introduced extra carbon into the deposit and both systems suffered from contamination by the air. Nevertheless, both methods lingered in use for several decades. The real breakthrough in arc welding came in the early years of this century when Oscar Kjellberg coated the bare wires to obtain better arcing and metallurgical properties. A few years later, in 1909, in London Strohmenger was encouraged by his friend Slaughter to devise a better coating than that employed by the Swedis welders, which was apparently applied by dipping just prior to use (6). The success of his asbestos-wrapped electrode led to the formation of the Quasi arc Company which produced this electrode for about three decades. The contribution of Strohmenger to what was one of the most significant developments in arc welding history has been almost totally ignored. A paper by Heaton in lf~14 (7) indicates that until this date, however, the Strohmenge electrode was used in the 'firecracker mode; that is it was laid on the work piece along the weld line and was not manipulated by hand.

At about the same time that coating were being applied to bare electrode wires, flash welding was developed from the Thomson butt welder, an resistance spot welding and thermit welding were invented. The paper by Heaton and its discussion reveal that the processes known at the time were gas; carbon-arc; bare wire metal-arc covered electrode metal-arc; resistance butt, spot and seam; and thermit, both with and without forge. By 1914 therefore, the major welding processes had all been invented. Act 1 was over and the stage was set for Act 2 'Establishing confidence'. This period was one in which welding was used for repair purposes and then cautiously for structural and general engineering. By the time of 'The Great Welding Symposium' held in London in 1935 (8). However, it could be said with some confidence that welding had arrived.

Next, there followed a brief but important period, 1935-1945, which could be described most accurately as' developing for production and proving in service'. Up until the early 1930s welding had been essentially manual, but now various mechanised forms appeared, notably the various resistance welding processes and submerged- arc. This was, of course, the period covered by World War II and the rearmament programme which preceded it. Much had to be done quickly and the advantages of welding for saving weight and speeding up fabrication were driven home in one application after another. Some of these achievements were recorded in a booklet published in the later 1940s by Sheet Metal Industries and entitled 'The Story of Electric Welding'.

The New Process or Scientific Period In the 25 years from the end of World War II until 1970 many new processes were developed. Every welding process requires energy in some form and with the exception of cold pressure welding this means a heat source. Every known method of generating heat locally became the basis of a new welding method and by 1970 every feasible heat source had been pressed into service. No fundamentally new processes have appeared since then. At the beginning of this period the inert gas shielded arc processes were devised and towards the end of the period electron beam and laser heat sources were being used for welding. Other methods originating in this period were friction welding and diffusion bonding, explosive, electroslag, magnetically impelled arc butt, ultrasonic and plasma welding. This period also saw the initiation of substantial research throughout the world and the identification of the major problems experienced with welds and welded structures. The problem of catastrophic fracture in ships and structures became understood and rules were formulated to allow the difficulty to be avoided. Fatigue, heat-affected zone (HAZ) cracking in steels, solidification cracking in both ferrous and austenitic steels and non-ferrous metals, porosity, radiographic and ultrasonic inspection methods and the scientific basis of welding processes were all subjects which were under continuous examination. It was a period when determined efforts were made to apply scientific, metallurgical and engineering principles to the development and use of welding; a time also when welding was applied to the rather suddenly increased range of metals and alloys which were brought into engineering science.

Prior to 1945 the materials welded in structural and general engineering were mainly mild steel, stainless steels, copper, and small quantities of pure aluminium. However, following World War II the pressure was on to weld low alloy steels, an increased range of stain-less and heat-resisting steels, aluminium alloys and copper alloys like aluminium bronze; also titanium and zirconium and their alloys and other refractory metals previously available only in limited quantities. These new materials were the output of the many metallurgical research laboratories set up in the period to develop new materials for higher performance and the developing new industries like jet engines and nuclear power. Any material must, sooner or later, be joined to itself or another material, and welding being an important joining method was actively considered in the development of these new materials. Naturally the new welding methods coming into existence at the same time were keenly investigated but the impact of the new processes on the bulk of steel fabrication was limited and only much later did steelmakers take the attitude to develop steels for welding rather than to develop welding for steel.

The quality and performance period 1970 has been chosen as the end of the new process period because after this date no fundamentally new processes were developed although there were many new variants of existing methods. There was by this time a choice of processes for any particular application, for example between flash welding and friction welding, or submerged-arc and electroslag, or tungsten arc and electron beam. The ultimate decision began to rest not just on technical considerations, but also on relative costs.

By this time also, the message that materials and particularly steels had to be developed with welding in mind, had been accepted. In no small measure this change in attitude by the steelmakers had been brought about by the requirements of the oil and gas industries for notch tough weldable steels (9). The requirements for notch tough welds in ship building initially hampered the wider use of high-productivity processes such as multiwire submerged-arc welding. Development of flux compositions overcame these problems to a large extent, but research and development on fluxes to achieve better weld toughness still continues. Multiwire submerged-arc welding is now in common use in ship construction.

It was the shipbuilding industry which gave an impetus to the application of mechanised welding methods and in this the Japanese shipyards played an important part. These early 1970 shipyard developments were automatic welding of a relatively high order, but not automation with adaptive control. Adaptive control may have one or both of two distinct functions (a) guidance of the welding device along the joint line or (b) automatic control of welding parameters to maintain weld quality.

Monitoring as a basis for quality control in welding operations was a subject much investigated, initially in the context of resistance welding. Later, when it became necessary to refine arc welding methods and to remove manual control, the measurement of welding parameters was studied to assist the application of automatic welding. The objective was to aid setting-up, improve reliability and provide a record for quality assurance purposes (10).

Throughout the 1970s the gas-shielded welding processes, which for the previous twenty years had been employed to weld special materials, became gradually more used on ferrous materials in the general engineering field. The plant for arc welding developed markedly with special electronically controlled power sources allowing the welding current to be pulsed to give improved control of the weld pool and greater consistency in operation. Such power sources can be set more accurately and readily switched between different settings (11). Specialised welding processes based on friction, electron beam and laser, invented prior to1970, also became firmly established. Aerospace and automobile manufacture are two industries which have had a particularly dominant role in advancing new methods, but for different reasons: aerospace for quality, and automobile component manufacture because the large numbers required justify investment in new methods. Both these industries adopted electron beam early in the development of the process and the automobile industry in particular has helped the development of other specialised processes such as friction and magnetically impelled arc welding. This industry has also provided the initial opportunities for robot technology.

Welding robots began to make their appearance on the welding scene from the mid-1970s as carders of spot welding heads for the manufacture of automobiles. These early robots were mainly of the pick and place variety and lacked positional accuracy, degrees of freedom and continuous path programming necessary for arc welding. These deficiencies were remedied quickly and for several years arc welding robots have been applied increasingly to the welding of automobiles and other small and medium-sized components. Arc welding robots employ gas metal arc (MIG) welding generally with carbon dioxide mixtures but sometimes using a self-shielding wire in which the protective materials are incorporated in a flux core to the wire. The power sources are designed to be switched from one procedure to another as required by the minicomputer controlling the whole system.

Ever since its development early this century, the coated metal arc electrode process has been under continuous development (12). In terms of the weight of weld metal deposited, it was, and still is, the most important single process. In the period since 1970, however, there has been a steady growth in the use of MIG and cored-wire systems in industrial countries at the expense of the manual metal arc (MMA) process. The present status is about 50/50, but the MIG and cored-wire processes (the continuous electrode processes) must continue to grow at the expense of MMA because they alone are suitable for the robotic and automated processes which are now becoming necessary.

3. PROCEDURE

A stainless steel sheet of dimension 1280mm*1200mm*1mm was provided. the sheet was cut in to four small pieces of equal dimension of 640mm*600mm*1mm using jigsaw(Bosch).the figure of the jig saw used in that particular operation is shown below.

Figure 1. Bosch jig saw

The sheet was clamped in the table and then was cut. One of the smaller sheet of equal dimension was taken and the sheet was cut in to small strips of width 30mm and length 640 mm. Lubricants are frequently used in order to provide better machining ,keeping moving parts apart ,reduce friction ,transfer heat, carry away contaminants and debris and reduce wear and tear. Then these small strips are cut into small plates of dimension 80mm*30mm*1mm.these small sheet are to be welded. After cutting in jigsaw the edges of the small sheets not polished. The surface of the sheets to be welded should be very smooth. So the surfaces are finished in grinding machine. To remove the bur filing was done.

After completion of finishing operation the stainless steel sheet, same procedure was followed for the copper sheet. Copper is very good conductor of heat so copper sheet gets heated very fast during grinding operation. So precaution was taken during grinding. Copper is a elastic material. So during sheet cutting and grinding deformation takes place. Due to high vibration of the jigsaw the copper sheet tend to deformation. So the process should be continued with very slowly and steadily. During grinding copper sheets may deform that will affect the welding process too much, so precaution was taken. After converting the big sheets of stainless steel and copper in to small sheets of dimension 80mm*30mm*1mm the small sheets are aligned on the table of the welding machine. The machine used to weld the two sheets of metal is given below.

LASER WELDING SETUP

Nd: YAG lasers are optically pumped using a flash lamp or laser diodes. They are one of the most common types of laser, and are used for many different applications. Nd:YAG lasers operate in both pulsed and continuous mode. Pulsed Nd:YAG lasers are typically operated in the so called Q-switching mode: An optical switch is inserted in the laser cavity waiting for a maximum population inversion in the neodymium ions before it opens. Then the light wave can run through the cavity, depopulating the excited laser medium at maximum population inversion. The amount of the neodymium dopant in the material varies according to its use. For continuous wave output, the doping is significantly lower than for pulsed lasers. The lightly doped CW rods can be optically distinguished by being less colored, almost white, while higher-doped rods are pink-purplish. Other common host materials for neodymium are: YLF (yttrium lithium fluoride, 1047 and 1053 nm), YVO_4 (yttrium orthovanadate, 1064 nm), and glass. A particular host material is chosen in order to obtain a desired combination of optical, mechanical, and thermal properties. Nd:YAG lasers and variants are pumped either by flash lamps, continuous gas discharge lamps, or near-infrared laser diodes (DPSS lasers). Prestabilized laser (PSL) types of Nd:YAG lasers have proved to be particularly useful in providing the main beams for gravitational wave interferometers such as LIGO, VIRGO, GEO600 and TAMA . Nd:YAG lasers are also used in manufacturing for engraving, etching, or marking a variety of metals and plastics. They are extensively used in manufacturing for cutting and welding steel and various alloys. For automotive applications (cutting and welding steel) the power levels are typically 1-5 kW. Super alloy drilling (for gas turbine parts) typically uses pulsed Nd:YAG lasers (millisecond pulses, not Q-switched). Nd:YAG lasers are also employed to make subsurface markings in transparent materials such as glass or acrylic glass.[14,15] The figure of welding machine is given below

Figure 2. Laser welding machine

The specification of the machine is given below

Power: 50 - 200W
Pulse Duration: 0.5 - 20 ms
Frequency: 0.5 to 20 Hz
Pulse Energy: Hasta 100 J
Peak power: 10 kW Hasta

The unique features of the machine are given below

- Available in power 75-200 Watts
- Ideal for the repair of moulds with addition
- Includes tables for the automatic movement and CNC
- Management easy and very intuitive.

The two sheets of different material are kept on the table of the welding machine. The edges are aligned properly and kept below the source of laser beam. Then we can check the sheets are perfectly aligned or not by viewing the alignment in the lens arrangement provided in the machine itself. Then we can simulate without using laser from which we can check whether the laser beam will incident on the line of contact of the too sheets or not. A camera is attached in the laser machine and a screen was provided. So we can check without laser before working with laser that the laser beam will b incident on the line of joining or not. We can adjust the sheets to align with the laser beam trajectory. After the alignment we can weld the two sheets. Special kinds of glasses are used to protect our eyes from the light emitted during welding process. Very intense lighting takes place during welding. We cannot see that in naked eyes because they may harm our eyes.

Grinding machine

The grinding machine is used to remove bur from the sheets of material. It consists of a electricity driven grinding wheel rotating at a particular speed. Provided with a bed with fixture to hold and guide the work piece. The grinding wheel can be controlled to machine a fixed work piece or the work piece can be moved against the grind head which stays in a fixed position. Better control of the grinding wheel or tables position is possible when a vernier calibrated hand wheel is used, or the features of numerical controls is used. Grinding machines removes material from the specimen by abrasion, which generates substantial amounts of heat; therefore coolant is used to cool the work piece to avoid overheating and go outside its tolerance. The coolant also helps the machinist as the heat generated may cause burns in some cases. In very high-precision grinding machines (most cylindrical and surface grinders) the final grinding stages are usually set up so that they remove very less amount per pass - this generates so little heat that even with no coolant, the temperature rise is negligible.

4. FACTORS EFFECTING LASER WELDING

Many factors have effects on laser welding quality .In this paper, the factors considered are

a) laser power
b) welding speed

4.1 laser power

Table 1. Varying laser power

Serial number	Laser power(in joules)	Welding speed(in mm/min)	Maximum tensile load(in KN)	Vickers hardness number
1	12	2	13.3	134.4
2	12.5	2	13.7	132.6
3	13	2	14.1	126.2
4	13.5	2	14.7	124.4
5	14	2	15.45	114.2
6	14.5	2	16.00	98.4
7	15	2	16.85	94.8
8	15.5	2	17.45	91.6

A set of experiment was taken on constant welding speed and keeping all other parameters constant except laser power. Laser power was varied between 12 joules to 16 joules and the specimens were passed through tensile and hardness test. Laser power was controlled by the machine directly. laser power can be varied as per requirement. The welding speed was kept 2 mm/min in this set of experiments. While laser beam diameter was kept 1.8mm, welding frequency was 12Hz.the table showing the variation of hardness and tensile strength when laser power changes is given in table 1.the graph of tensile strength v/s welding power and hardness v/s welding power are given below

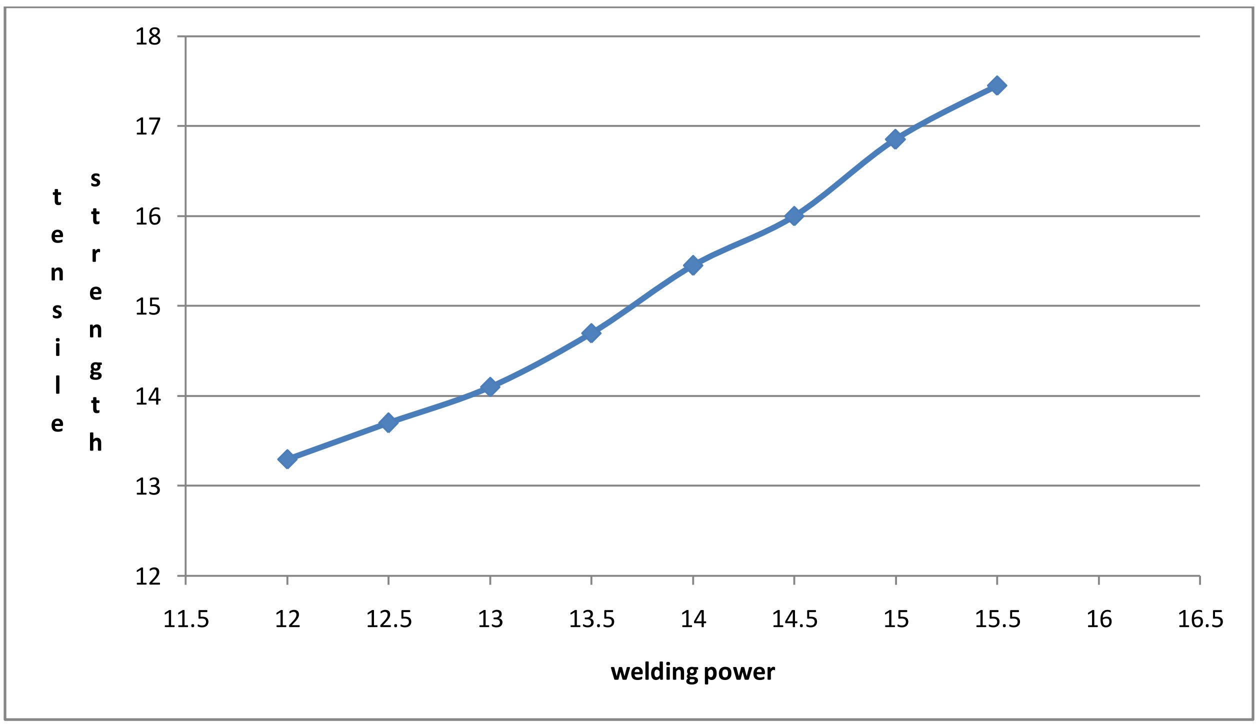

Figure 3. Graph of tensile strength v/s welding power

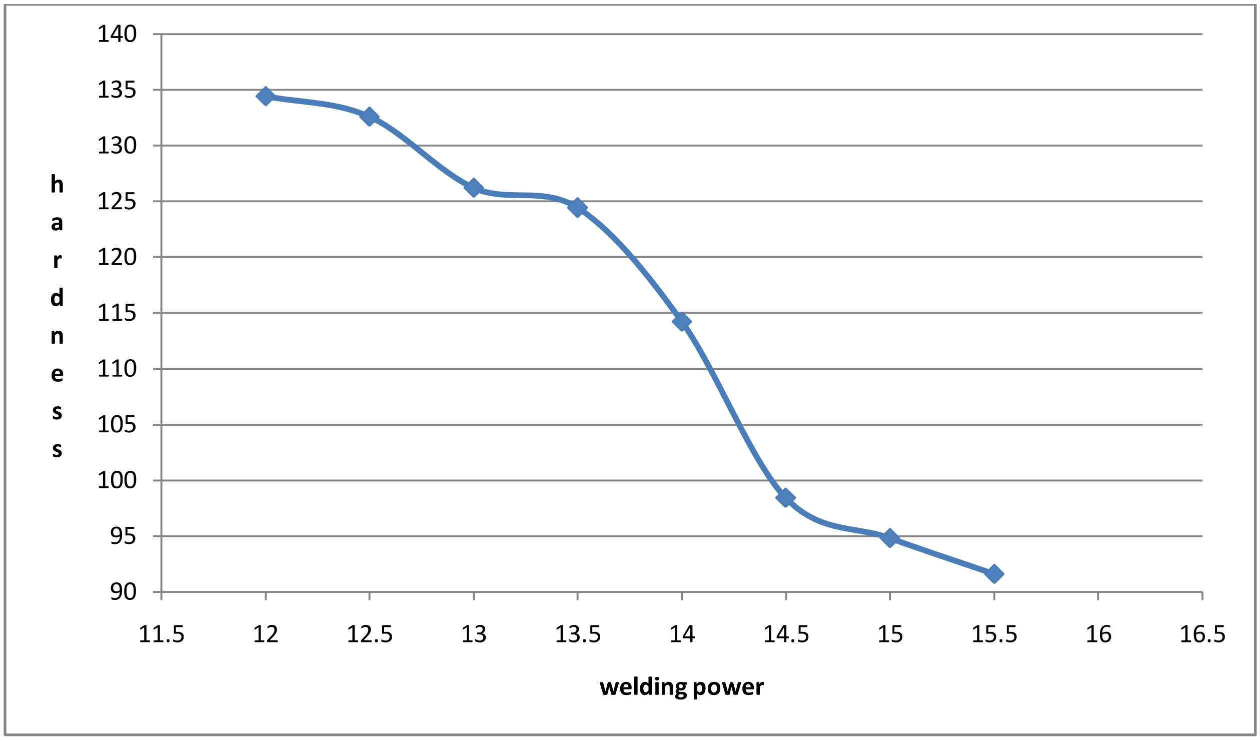

Figure 4. Graph of hardness v/s welding power

4.2 Welding speed

After varying laser power a set of experiment was done varying welding speed of the laser beam. Laser power was 10 joules, frequency 11 Hz, weld spot diameter 1.8mm.the welding speed was varied from 2 mm/min to 3.4 mm/min. So from this the variation of tensile strength and hardness of the joint was tested. The speed was controlled by cnc. The required value of welding speed was only fed to the computer connected to the machine. The machine welded the sheets automatically with the particular speed in each experiment.

The variation of tensile strength and hardness with change is welding speed is given below

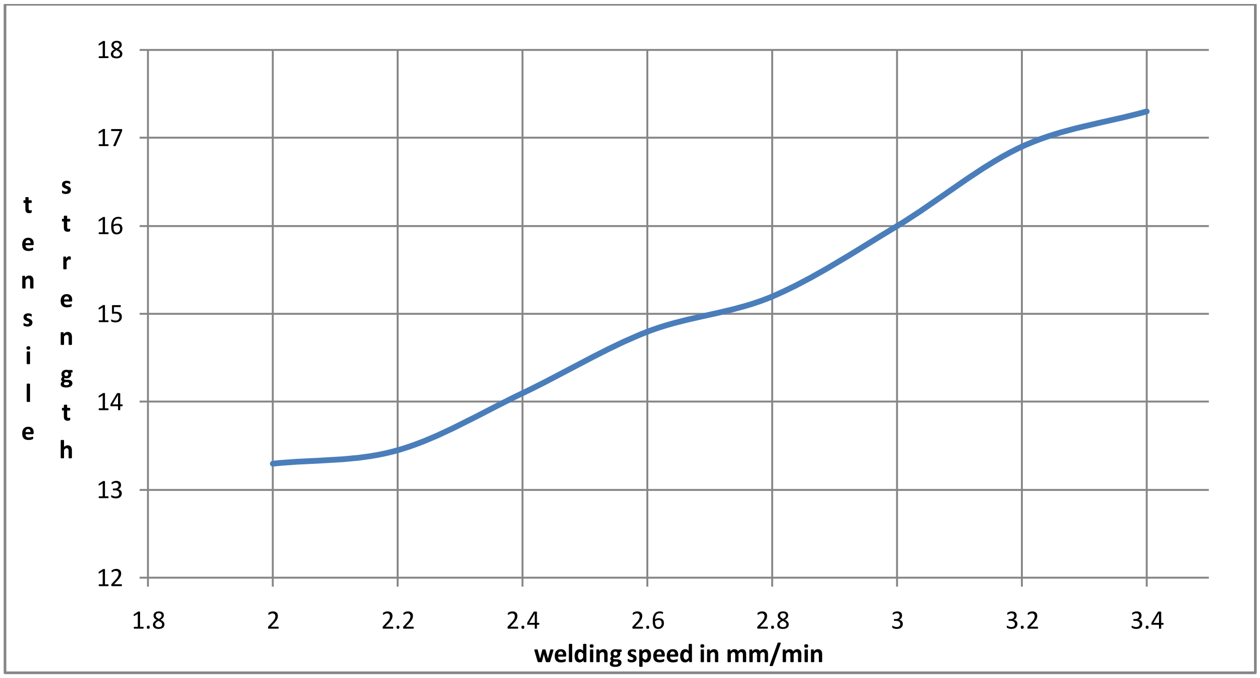

Figure 5. Tensile strength v/s welding speed

Table 2. Varying welding speed

Serial number	Laser power(in joules)	Welding speed(in mm/min)	Maximum tensile load(in KN)	Vickers hardness number
1	10	2.0	13.30	58.3
2	10	2.2	13.45	61.7
3	10	2.4	14.10	64.2
4	10	2.6	14.80	68.7
5	10	2.8	15.20	69.1
6	10	3.0	16.00	71.9
7	10	3.2	16.90	73.8
8	10	3.4	17.30	76.5

Figure 6. Hardness v/s welding speed

5 ANALYSIS OF WELDING PERFORMANCE

5.1 Tensile test

The main aim of the tensile test is to evaluate the strength and plasticity of welding joints and examine the influence of welding defects on the joint performance. The test can be done on universal test machine. The tensile test results of laser welding joints show that the yield strength and the tensile strength .in universal testing machine the specimen is clamped at both ends. The machine is hydraulically operated. The moving part of the machine was controlled manually. It is moved as per the specimen. The machine was reset if it shows any nonzero value. Then the machine was switched on. Then the tar load was removed from the computer. Then the tensile test is started. The graph is plotted in the computer screen. From which we can see the deflection. A sample graph is shown below.

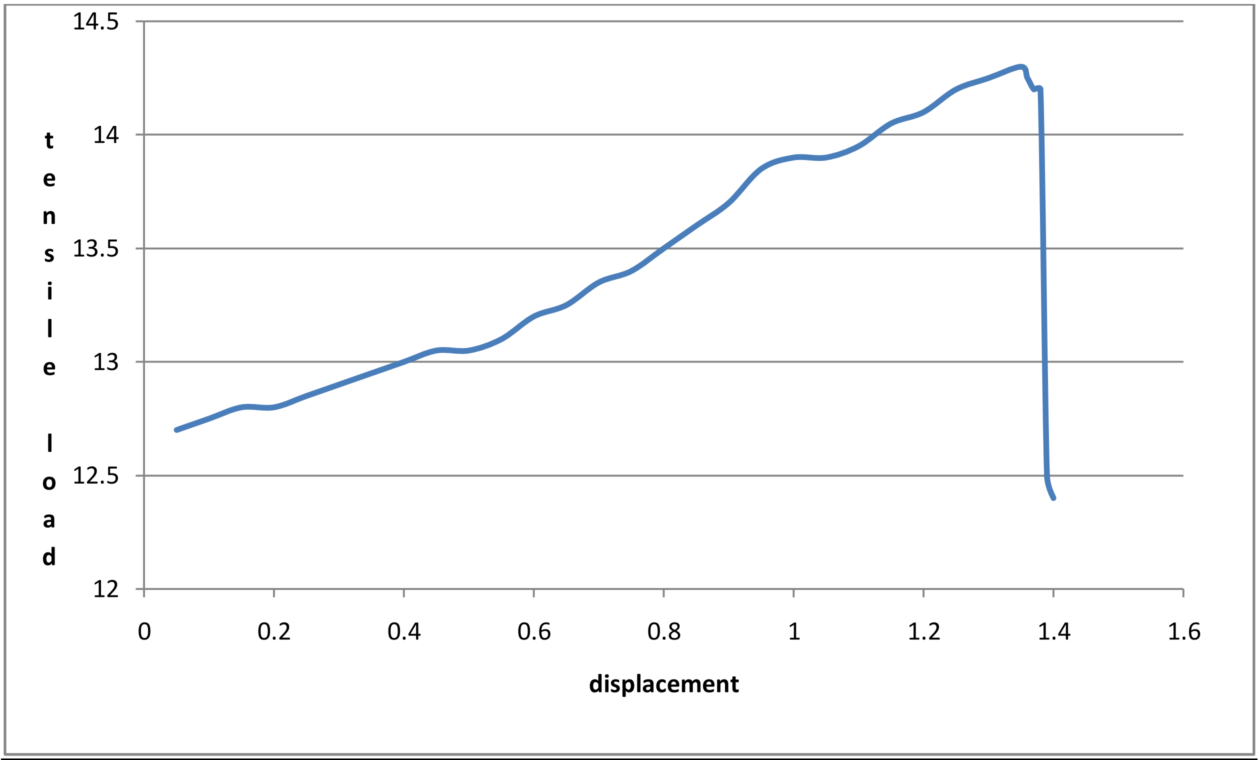

Figure 7. Tesile load v/s displacement

From the graph the maximum load at which the specimen broke can be calculated. The deflection at each point can be observed. Deflection at each applied load can be seen. The load was applied hydraulically. After reaching the breaking stress the specimen broke. A breaking sound came from the specimen. Then the test was stopped and the maximum tensile stress applied was noticed. The figure of universal testing machine is given below

Figure 8. Universal testing machine set up

5.2 Hardness test

Hardness of the welding joint was measured in Vickers hardness apparatus. In this apparatus the specimen is kept on a circular plane. The plane can be moved upward or downward as per requirement .the surface of the specimen of which hardness is to be measured should be perfectly plane and polished. The specimen is kept on the circular plate. Then the light source was indent on the point on the weld joint, where the hardness to be measured. Then the light source is replaced by the tool with diamond edge. The tool is then pressed deeply on the surface of the weld joint. Then a diamond shape is marked on the weld surface. Then the lengths of both the diagonals were calculated. From the diagonals we can find the Vickers hardness number. The hardness can be measured 3-5 times in each area and the average can be taken as the test results. By varying the load different observations can be taken. The figure of the machine is given below

Figure 9. Vickers hardness testing apparatus

This machine has many unique features. Some of the specifications of this instrument are

- Various model covering scales from HV0.3 to HV50.
- Measurement accuracy conforms to EN-ISO6507
- Display conversion to Rockwell, Superficial Rockwell, Brinell, shore and Tensile
- Objective: 5X&10X or 10X&20X. Eyepiece : 15X
- Built-in printer and RS232 output
- Also available: Model for Rockwell Hardness Test, Brinell Hardness Test, Micro Vickers Hardness Test and Universal Hardness Test.[23,24]

6. CONCLUSION

From graphs we can see that with increase in welding power tensile strength increases but hardness decreases. With the increase in welding speed, both tensile strength and hardness of the welding joint increases.

There is many possibility of occurrence of error in the experiments. Some of main reasons are

- The cutting process is not accurate due to very high vibration of the jigsaw.
- After finishing process very small amount of bur may change the welding characteristics.
- The two sheets do not always meet each other in a line.
- While welding the alignment may be disturbed due to vibration of the sheet above the weld table.
- After welding the welding joints were a bit tilted due to incident of high energy laser impact.
- There may be some error due to the bending of the weld joint after welding in the hardness test.

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